

EVOLUTION OF MINIATURE DETECTORS AND FOCAL PLANE ARRAYS FOR INFRARED SENSORS

by

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1. INTRODUCTION

Sensors that are sensitive in the infrared spectral region have been under continuous development since the WW-II era. A quest for the military advantage of "seeing in the dark" has pushed thermal imaging technology toward high spatial and temporal resolution for night vision equipment, fire control, search track, and seeker "homing" guidance sensing devices. Similarly, scientific applications have pushed spectral resolution for chemical analysis, remote sensing of earth resources, and astronomical exploration applications.

As a result of these developments, focal plane arrays (FPA) are now available with sufficient sensitivity for both high spatial and narrow bandwidth spectral resolution imaging over large fields of view.¹ Such devices combined with emerging opto- electronic developments in integrated FPA data processing techniques can yield miniature sensors capable of imaging reflected sunlight in the near IR, and emitted thermal energy in the Mid-wave (MWIR) and longwave (LWIR) IR spectral regions. Robotic space sensors equipped with advanced versions of these FPAs will provide high resolution "pictures" of their surroundings, perform remote analysis of solid, liquid, and gas matter, or selectively look for "signatures" of specific objects. Evolutionary trends and projections of future low power micro detector FPA developments for day/night operation or use in adverse viewing conditions are presented in the following test.

2. DEVELOPMENT TIMELINE

Figure 2-1 shows a chronological progression of IR technology development in the U.S. spanning the technology from single element bolometer devices to large scale arrays of high performance MWIR and LWIR detectors having tens of thousands of elements. This chart shows the evolution of supporting semiconductor technology and materials processing techniques that enabled the development of various detector types of ever increasing performance at longer wavelengths. Shown on the upper part of the chart are those developments which ultimately led to FPAs with large numbers of micrometer sized detector elements processed with integrated circuit (IC) micro-electronic manufacturing processes. It is these arrays that have evolved over the past few decades that can provide the "smart eyes" for future space exploration equipment.

3. LIMITING TECHNOLOGIES

In projecting future trends for a specific field, it is often enlightening to review past limiting technologies as a function of time. The way in which seemingly impenetrable barriers have been broken-through by a new paradigm-shift can indicate potential means of overcoming current limitations to achieve even better future performance either in terms of sensitivity (SNR) or smaller lighter more capable systems. For example, early IR detectors (1940's) responded to thermal emissions from a scene by being heated and cooled by the incident energy, with variations in the detector material's physical properties (electrical resistance or capacitance,) being instrumented as a measure of the observed IR signal strength. These cyclic variations in the detector temperature were not sufficiently rapid for "raster scanning" of a scene to produce a usable image. Thus it appeared that the laws of physics limited the achievable detector speed or electrical bandwidth by the thermal mass of these bolometer

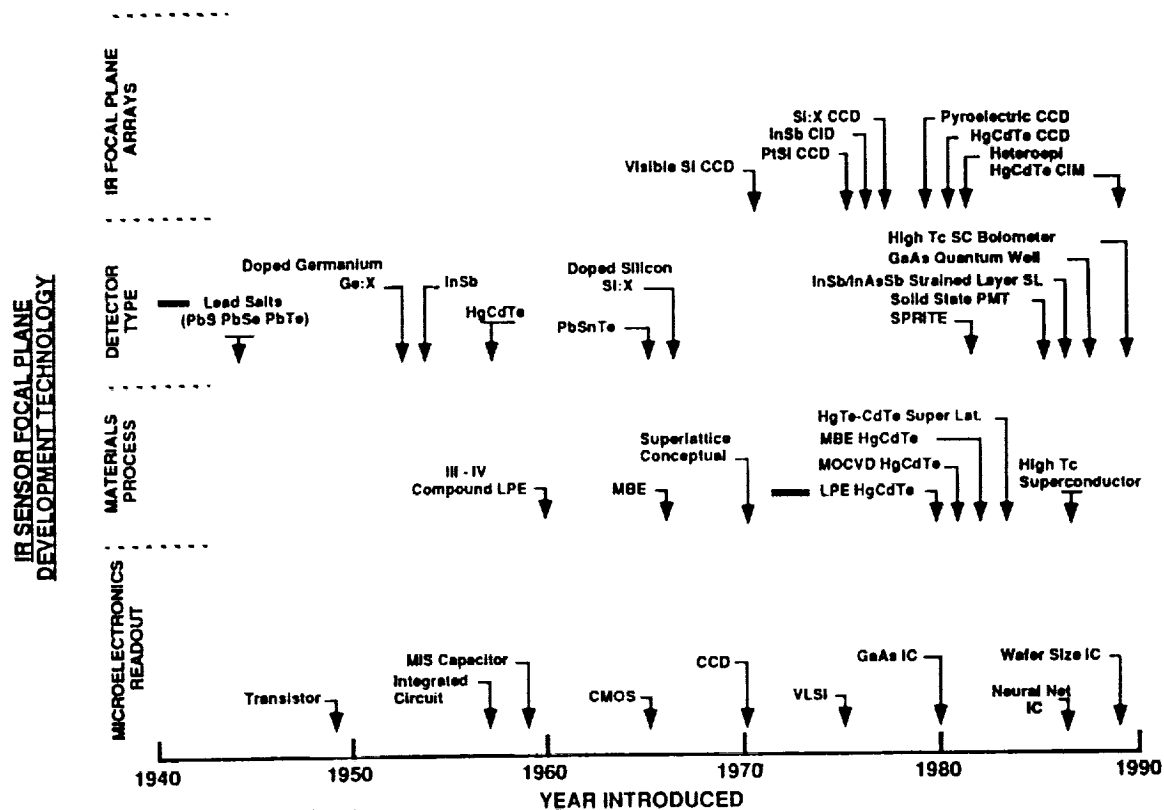


FIGURE 2-1 Infrared Detector and Focal plane array Development Timeline

devices, and by the attachment of electrical leads which in effect form a degrading heat-sink for the sensitive sensing element. The advent of semiconductor materials development in the 1950s and 1960s, however, provided the "break-through" that led to the development of quantum IR detectors capable of sensing photons with high electrical band-width. A host of military applications pushed the development of these IR sensing semiconductor photoconductors (PC), specifically for near IR (NIR), MWIR, and LWIR spectral regions.

Photo lithography, metalization, selective chemical etching, and micro wire bonding processes developed for the transistor and IC industry were applied to IR detector manufacture yielding arrays of PC detectors used for parallel-scanned imaging systems (FLIRS). The limiting technology thus shifted from the previous slow-responding detectors, to a detectability versus field of view/resolution limitation caused by the excessive bias power dissipation load from many PC detectors on a cooled FPA. Bias power and electrical lead heat-loading were the significant limitation problems for the LWIR applications where stable cryogenic cooling of the FPA is required for proper operation.

To circumvent this power load limitation and achieve even higher bandwidths, the new semiconductor technology was used to fabricate PN junction diode devices which act as photovoltaic (PV) IR detectors. This change in configuration results in high impedance detectors that need little bias current as do the previous PC devices.

Eliminating the bias power limitation through these PV diodes still left the electrical interconnection leads as the dominant limitation on the number of detector elements that could be used in linear or two-dimensional IR detector arrays within a cryo cooled Dewar package. A large number of leads presents a significant heat load on the FPA cooling, and requires a large physical package to support the large number of hermetically sealed low-noise vacuum

feedthroughs required to conduct the low-level detector signals out of the Dewar. The number of electrical leads or Dewar "real estate" needed for interconnections thus for several years became the limiting technology for PV detectors of InSb and HgCdTe arrays. The emergence of charge coupled devices (CCD) and charge Injection Devices (CID) provided a means of multiplexing the IR detector on the FPA and allow packaging large numbers of detectors in small practical sensors. Arrays of 1024×1024 are available for near IR sensing detectors, and 640×480 element arrays of In Sb & Hg Cd Te for the MWIR and LWIR regions.^{2,3} Figure 2-1 summarizes the described chronological development process and Figure 3-1 shows the number-of-detector elements and electrical-bandwidth tradeoffs required for various application requirements.

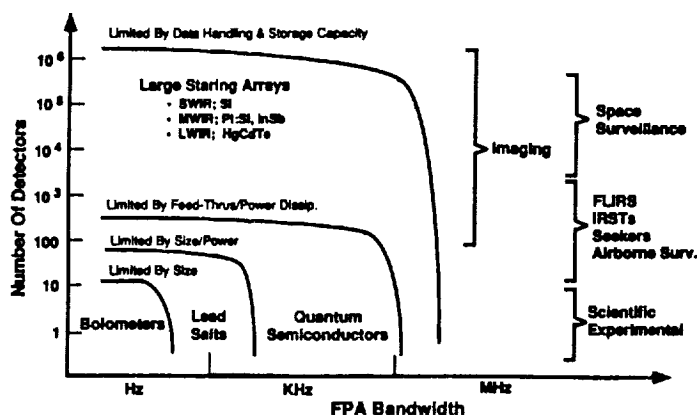


FIGURE 3-1
General Infrared Detector Requirements

4. CURRENT DETECTOR STATUS

Semiconductor quantum detectors are available to cover the IR spectrum; with silicon-based devices (Pt:Si) covering the near IR region, In Sb the MWIR ($3-5 \mu$) region, and HgCdTe devices the LWIR ($8-12 \mu$) region. Because HgCdTe is "tunable" with stoichiometric composition, one material can be used over the IR band to approximately 12μ wavelength. For wavelengths beyond this $8-14 \mu$ atmospheric window, extrinsic silicon and germanium devices cooled to approximately 20K are generally used.

Detector arrays from these materials are made with quantum efficiencies (Q_e) approaching the theoretical limit, element (pixel) sizes matching the diffraction limited optical spread function of reasonably fast ($f/2$) optical systems, and formats approximating standard television frame/display resolutions. These then are approaching the physical performance limits for semiconductor quantum photon detectors.

Readout devices using CCD and CID technologies are being superseded by integrating source-follower and capacitance transimpedance integrating amplifier (CTIA) integrated circuits that have ultra low-noise read rates of tens of megahertz. Thus, the capability of PC and PV semiconductor detector and silicon readout FPA combination is currently limited by the physics of the detection process and the interface electronic data handling capacity of the FPA. Clock signals, bias inputs, and non-uniformity correction circuitry add complexity to most FPAs, and thus tend to limit the miniaturization of sensors. On-chip processors are clearly needed.

Silicon based detector arrays used in the visible and near IR (or Pt:Si for MWIR) applications can be made in very large mega-pixel formats when used with silicon IC readout and data handling circuitry. Conversely, hybrid IR FPAs for the LWIR region using other detector materials bonded to silicon microelectronic devices are limited in physical size (number of pixels) to approximately 500-600 elements across because the differential thermal expansion properties of the dissimilar materials tends to stress and separate the hybridized assembly when repeatedly cycled to cryogenic operating temperatures. In spite of these limitations, current IR focal plane technology is clearly adequate for high reliability space applications

providing both high spatial and spectral resolution for imaging and scientific remote sensing spectral signature analysis in spectroscopy applications. But for micro-miniaturized sensors of comparable capability to current hardware, monolithic FPAs made with common detector/readout materials will be required to cover the spectrum in large formats, and these monolithic devices must include integral binary optical elements with on-FPA opto-electronic data processing for compactness.

Figure 4-1 presents a tabulation of some leading off-the-shelf large area imaging IR detector arrays along with their performance characteristics.

5. EMERGING TECHNOLOGIES FOR MINIATURE FPAs

Many new IR detector concepts are being reported in the literature including; quantum-well structures, superlattices, superconductor based detectors, and microstructures which act like tuned "antenna" arrays.⁴ Some of these concepts are variations on current technology, and some are truly new concepts that have the potential for significant improvements in covering larger spectrum regions more efficiently. It is beyond the scope of this paper to describe all of these new device concepts, but some clearly are applicable to effective miniaturization of sensors. Among the more promising new technologies that support a progressive stepwise "roadmap" from currently available technology to robust space sensors are the following:

1. Binary Optics
2. On-chip processing electronics
3. Un-cooled detectors
4. Pattern recognition (Neural Nets)
5. Spectrally selective detector assemblies

Binary Optical Elements For FPA Applications: The term binary or holographic optics refers to diffraction-based optical elements made with well developed silicon micro-electronic photo-etching processes. Etched patterns on transmitting or reflecting surfaces can be designed to perform the functions of traditional optical components; including anti-reflection (AR) coatings filters, lenses, prisms, and indeed other functions not feasible in conventional optical elements. These binary elements are designed with common electrical engineering calculations (Maxwell's equations) and manufactured by standard micro electronic IC fabrication processes to form unusually powerful FPA assemblies.

"Moth-eye" AR coatings and micro-lens arrays are the more common binary optics used for FPA performance enhancements. The moth-eye AR surface is a pattern that is etched into an optical element and thus is not subject to separation and peeling degradation as are conventional AR coatings of dissimilar materials. These diffractive optics AR surfaces are generally "tuned" to a desired passband where the performance can surpass even expensive multi-layer coatings. Figure 5-1 shows a typical moth-eye AR coating etched into a silicon surface. Micro-lens arrays are used in conjunction with detector arrays as proximal field lenses, one for each element in the detector array. In this configuration, the lenses condense each focal plane pixel onto a detector element which thus can be much smaller than the pixel by the magnification ratio of the lens. Thus the FPA retains a 100% fill-factor while the detectors are spaced to allow for processing electronics to be located between the elements. See figure 5-2.

Lenslet arrays sandwiched with spatial filter patterns are capable of on-FPA optical computing for pattern recognition and other pre-processing techniques intended to reduce the data handling loads. These and other binary optics and "retinal" FPA processing techniques are discussed in detail by W.Veldkamp in an other part of this workshop report, and hence will not be repeated here.

	A	B	C	D	E	F	G	H	I	J
1		Amber	Amber	Rockwell	Rockwell	Rockwell	SBRC	SBRC	Cincinnati E.	Cincinnati E.
2	Type	InSb	InSb	SWIR HCT	SWIR HCT	SWIR HCT	InSb	InSb	InSb	InSb
3	Format	256x256	512x512	256x256	256x256	640x480	256x256	640x480	256x256	160x120
4	Pitch (microns)	38	25	40	40	27	30	20	30	50
5	Readout Type	DI	DI	DI	CTIA	DI	Source Follower	DI	Source Follower	DI
6	Frame Rate	250 Hz @4MHz	60Hz @4MHz	300+ 1@20MHz	300+ 1@20MHz	60+ 4@5.8MHz	60/(100 Hz?)	4Hz	4Hz	100Hz
7	Dark Current	1900 e/s @50K		1200e @50K	1200e @50K		<400e/s @50K	30e/s @40K	30e/s @40K	
8	Storage Capacity	1.6E7e	5E6e	4E7e	0.2-1.0E6e	1.28E6e	6E5e		3E5e	3.50E+07
9	Read Noise @60Hz	400e?	400e?	<400e	10-50e (100easy)	<500e	<300e/150typ	1200e	30e	1500e
10	Quant Noise	400e?	400e?	approx = read	Included above	approx = read				
11	Quantum Efficiency	50-80%AR	50-80%AR	60-90%	60-90%	60-90%	>80%	>80%	70%	70%
12	Spectral	>1.0?	>1.0?	>0.8 micron	>0.8 micron	>0.8 micron	>0.3 microns	>0.3 microns	1-5.4microns	1-5.4microns
13	Operability	98% spec	95%?	99%	99%	97%	>99%	>99%	>99%	>99%
14	How defined	1/2 D*	1/2 D*	1/2 D*	1/2 D*	1/2 D*	3*NEP			
15	Binning	Yes	No	No	No	No	No			
16	Status	OTS	Fanout develop	OTS	Designed only	Imaged	OTS	Hybridized	Delivered	OTS
17	Comments			Reset ripple	Reset;global,ripple or non destructive	Designed shuttered	5MHz bursting		Crosstalk<.1%	Crosstalk<.1%
18		250 Hz frame					Reset,Ripple or Non Destructive			
19										

FIGURE 4-1 Currently Available Large Area Imaging IR Arrays

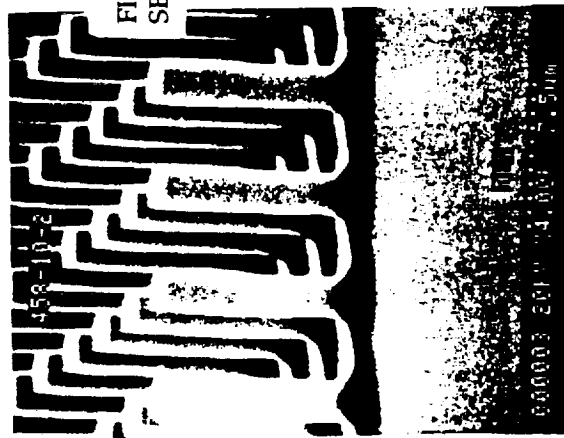


FIGURE 5-1
SEM Photo Of "Motheyc" Microstructure

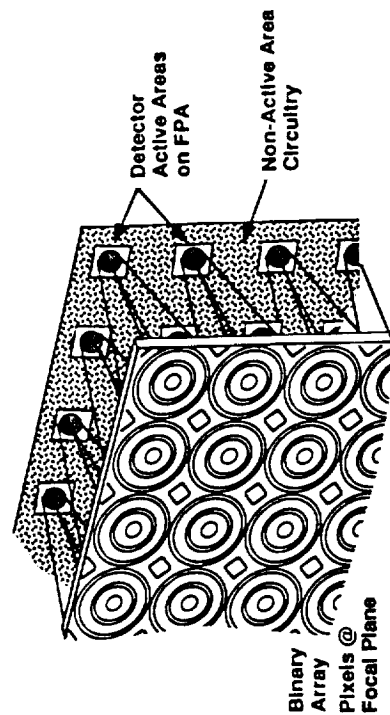


FIGURE 5-2
Binary Optics Lenslets Used To Correct "Fill-factor" And Allow Space For On-FPA Processing Electronic Circuitry

Other micro-structure devices, related to binary optics in terms of design and fabrication processes have been developed for sensor applications. Micro-bolometer IR detector arrays and "resonant structures" are examples of devices usable for robust IR detection. The bolometer arrays are described in a subsequent section. Resonant structure technology being developed by the Honeywell Sensor and Systems Development Center in Bloomington, Mn., represents an emerging trend in monolithic sensor fabrication for low power, rugged, and highly reliable sensor elements that clearly are applicable to space exploration applications, and warrants further description here.

Silicon-based resonant sensors (RS) are micron sized structures made with mature silicon processing technology. The principle of operation is to measure a shift in the resonant frequency of a microbeam as some force is applied to the structure thereby straining the beam. Equipped with integral monolithic silicon drive/sense and buffer circuitry, these devices are very small extremely robust self contained sensor elements providing digital output signals directly. Because the operating mechanism senses "time-base" variations (frequency) rather than electrical property changes, resonant structure sensors are inherently stable in operational calibration. The resonant micro-structure device is capable of sensitive wide dynamic range operation, and under adverse environmental conditions. Configured properly, these devices can be used for strain gages, pressure sensors, accelerometers, and sealed "Golay cell" thermal energy detectors. Figure 5-3 shows the RS principle of operation, and 5-4 diagrams a pressure sensor or accelerometer concept. Figure 5-5 shows an electron microscope view of an encapsulated micro-beam RS with the driver contact in place (light colored area)

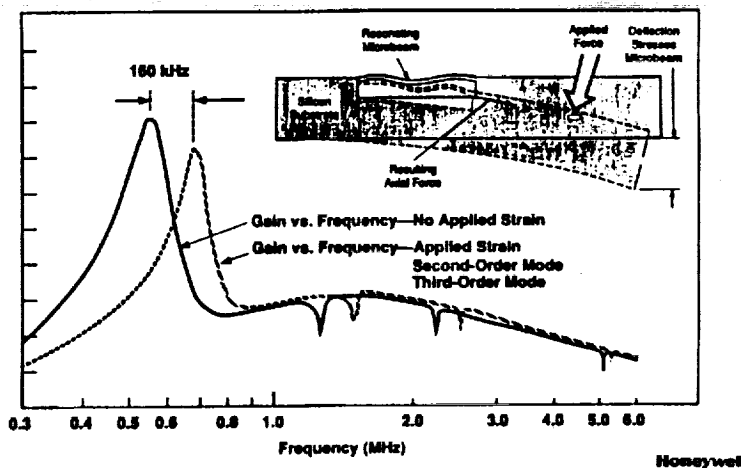


FIGURE 5-3
Resonant Structure;
Principle Of Operation

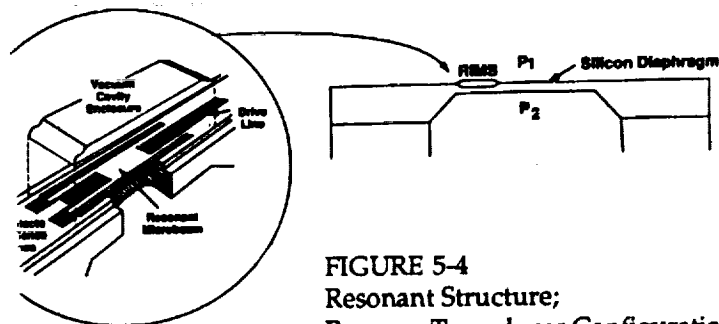


FIGURE 5-4
Resonant Structure;
Pressure Transducer Configuration

On FPA chip processing electronics: A practical "next step" toward miniaturization of sensors is to integrate onto the detector focal plane array sufficient electronic signal to provide ultra low-noise detection, internal clock generation, time delay integration of spectral analysis on two-dimensional arrays, and a robust simple interface to external electronics. Rockwell International has developed SWIR Hg Cd Te FPAs with these features⁵ and intends to exploit them for upcoming NASA space applications. R.I. also has extended their on-chip processing to include correlated double sampling, selectable integration capacitors, and externally selectable high pass filter banks all working in the "charge domain" within the FPA readout device. These semi-programmable SWIR devices operate with ultra-low noise (10s of electrons) at 90K operating temperature, and about 100 electrons at thermo electric cooling temperatures of 150-200K. An integrated chip/TE cooler assembly of this type forms a large part of a SWIR sensor, replacing large bulky electronics, cryo-coolers, and interconnection cabling.

Amber Engineering in Santa Barbara California has recently announced a 256x256 pixel detector of indium- Antimonide (In Sb) equipped with an integrated "massively parallel processed" signal processor chip.⁶ This device operates in the MWIR (3-5 μ) spectral region and forms the heart of an effective thermal imaging system.

Irvine Sensors in Irvine, California has pursued processing of FPA signals through "Z-plane" technology where electronic circuitry is stacked in the "z" dimension behind two dimensional staring mode X-Y detector arrays. A recent development involves a densely packed 3-dimensional computer-processor to perform processing algorithms from the IR array output data.⁷ Among the functions being performed by the Z-technology is "data extraction" via neural network type processing; a form of "smart" data compression to facilitate data flow from the FPA. This technology is exceptionally compatible with current detector arrays for near term miniaturization of Space Sensors. Figure 5-6 shows a 128 X 128 element detector array packaged with electronics to perform all of the clocking and read-out functions, and additionally includes a neural net type computer and controllable filter bank to facilitate image processing functions. This assembly represents a significant step in miniaturization of smart sensors that can perform edge-enhancement, pattern recognition, motion detection trajectory prediction, and other such functions with minimal interface with external computer equipment.

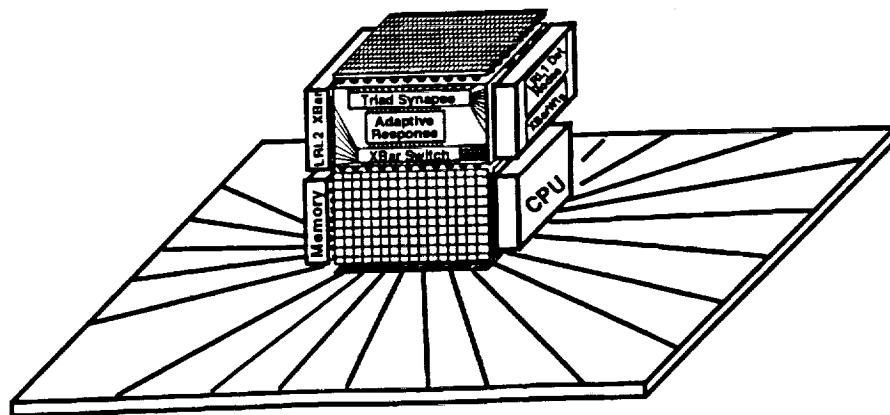


FIGURE 5-6 Irvine Sensors Integrated IR Detector/Processor Module

Uncooled Detector Development: There has been a large general effort to develop IR detectors that do not require cryogenic cooling because cryo-coolers are bulky, heavy, and consume large amounts of power. Liquid cryogenics present a logistics problem for space applications, and radiative coolers are bulky and somewhat delicate. Thus, uncooled IR detectors are very desirable to avoid the cooling problem.

Classic lead-salt (PbS, PbSe) SWIR and MWIR detectors although somewhat slow electrically, when combined with modern read out devices and operating in a staring mod, have sufficient electrical bandwidth for imaging operation with high sensitivity in the 1-5 micron region. Several vendors including Optoelectronics Inc., Petaluma California provide such detector-readout combination devices.

Pyro-electric and ferro-electric detectors have been developed for imaging sensors by Texas Instruments in Dallas, Texas and others. These devices are essentially thermally modulated electrical capacitors, and can be operated uncooled or in a "temperature stabilized" mode with a single-stage TE cooler. Pyro/ferro electric devices offer a relatively near term potential for space sensors in specific applications where high sensitivity and electrical bandwidth are not necessary.

A relatively new non-cooled (but TE stabilized) detector technology consisting of arrays of micro-bolometers has been pursued by Honeywell for the U.S. Army CECOM for Night vision and electro-optics.⁷ These devices, developed under the High Density Array Development (HIDAD) program are thin-film micro bolometers made in 240x336 pixel arrays of 2-mil square elements. Operating in the LWIR (8-12 micron) spectral region, these devices are unique for uncooled detectors in that optical chopping or modulated IR radiation is not required for their detection mechanism. NEDT sensitivities of 0.09C and frame rates of 30Hz are reported for the 240-336 element arrays. Clearly this rugged detector technology made by conventional sequential metalization and etching processes on silicon material and which require no cryogenic-cooling is worthy of development for space sensor applications. Figure 5-7 shows a typical thin film HIDAD pixel element concept.

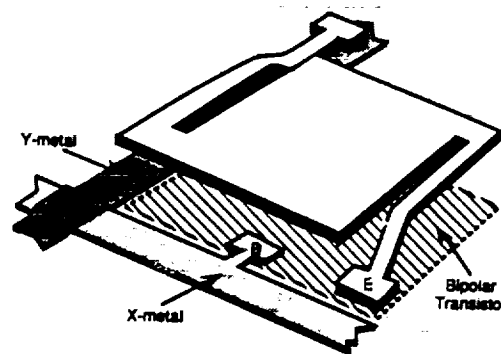


FIGURE 5-7
HIDAD Microbolometer IR
Detector Element Concept

On-FPA Pattern Recognition & Artificial Neural Networks (ANN) An electronic means of providing on-FPA signal processing by high density electronic packaging was discussed above in describing the Z-plane technology. A "next step" in developing "smart" focal planes is to build complex FPAs with layered structures of optical spatial filters, binary diffraction optical elements, and active silicon circuitry. Such opto-electronic FPAs can approximate trainable neural nets with the physical layers arranged as "layers" of neuron nodes in the ANN. These compact rugged low power detector/processor devices thus can become the "smart" building blocks for sensors intended to look for specific EOIR signatures, objects, events or other spatial/spectral patterns. For non-spectrographic applications the ANN can be used to pre-process the large volume of data from complex two dimensional FPAs sending only the pertinent information from the sensor for further processing. These devices thus perform a data-compaction function for applications interested only in thematic changes, moving objects, or transient events. Edge enhancement and 'nearest neighbor' pixel suppression for contrast

improvement and other SNR improvement processes significantly improve the performance of smart sensors which can be made in micro-miniature sizes.

Spectrally Selective Detectors. Quantum detectors of HgCdTe are being fabricated on graded electrical band-gap PN junctions where photo diodes implanted at various physical locations along this graded-gap region will respond to different wavelengths of incident IR flux. See figure 5-8. Because the graded gap crystal material is formed by varying the constituents of the $Hg_{(1-x)}Cd_xTe$ during the crystal growth process, the optical index of-refraction also varies with location across the gap. With proper geometry and material stoichiometry combined with etched binary optic diffractive patterns, a single chip self contained spectrometer for moderate spectral band-widths can be constructed. The bulk associated with optics, spectrographs, filters,etc. are thereby eliminated.

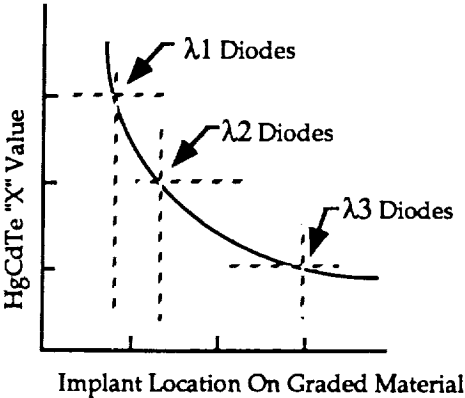


FIGURE 5-8 Graded Band-Gap HgCdTe Allows Monolithic Spectrally Selective Detectors

6. CONCLUSIONS AND RECOMMENDATIONS

Technology exists in varying degrees of development maturity from which to fabricate micro miniaturized IR sensors specifically designed for near automated space flight applications. Such "smart" sensors range from thermal imagers with low data rate interfaces to hyperspectral sensors capable of performance rivaling systems like the AVIRIS, but operating in the extended IR spectrum; and all contained on a micro-chip based focal plane assembly. Long term development of "virtual reality" human interface systems will then allow for man-in-the-loop operation of remote exploration tools (Moon, mars) in day/night conditions. The key to these useful virtual interfaces is to have sufficient "environmental" data to recreate the scene at a remote location so that the operator feels that he is actually "in" the real scene. Sensors can be available to accumulate such data for space exploration applications if certain technologies are developed in the proper sequence.

Figure 6-1 shows a time sequenced "road map" of IR FPA and processor/readout schemes that can lead to these advanced systems when the appropriate technology has been developed.

	Detectors	Readouts	Applications	
0-3 Years	<ul style="list-style-type: none"> • Si • PtSi • InSb • HgCdTe 	<ul style="list-style-type: none"> • Direct Injection CCD • CTIA • SFD 	<ul style="list-style-type: none"> • Thermal Imager • Spectrometer • Imagery Spectrometer 	➔ Earth Observation Planetary Observation Telescopes
3-5 Years	<ul style="list-style-type: none"> • Uncooled Tech. • On Chip Filter 	<ul style="list-style-type: none"> • Parallel Processing • Neural Operator 	<ul style="list-style-type: none"> • Smart Automated Sensors 	➔ Orbiting Telescopes
5-10 Years	<ul style="list-style-type: none"> • Spectral Detector 	<ul style="list-style-type: none"> • Complex Integrator • Optronic Processor (Amichronic) 	<ul style="list-style-type: none"> • Smart Sensors • Virtual Reality Output 	➔ General Purpose Remote Sensing

FIGURE 6-1 Progressive Development Of Increasingly More Complex IR Sensors

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Microtechnologies
and
Applications to Space Systems Workshop

MICROSPACECRAFT

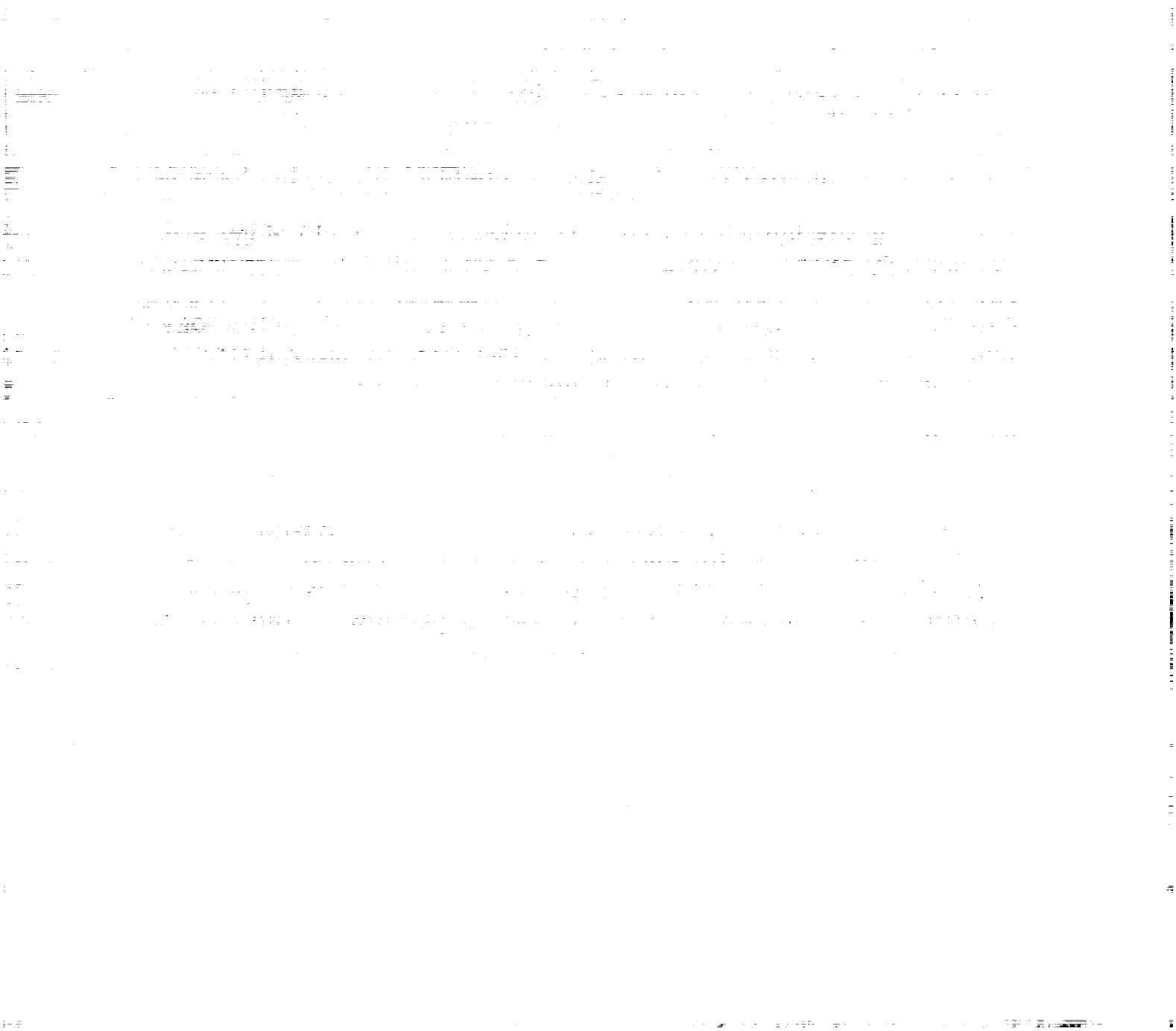
ASTEROID INVESTIGATION WITH MICROSPACECRAFT (AIM)

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ABSTRACT

Technology development by SDIO and other sources over the past several years has produced many high performance miniaturized spacecraft components. Although many of these components were designed for short operational lifetimes, some may be applicable to longer missions. The intent of the AIM design effort was to develop a conceptual microspacecraft system using SDIO-like technology to perform a near Earth asteroid (or comet) imaging science mission from a Pegasus launch vehicle. To achieve this, technology was deliberately pushed beyond state-of-the-art in all subsystem areas. Although the components and technologies used are based on the capabilities of current laboratory prototypes and technology demonstration devices, this conceptual spacecraft design will require some significant amount of development to be realized.

The AIM microspacecraft concept is envisioned as a ~ 25 kg, 0.5 m diameter by 0.6 m high hexagonal cylinder capable of conducting an imaging asteroid (or comet) flyby and returning the data to Earth. It is launched into low Earth orbit three to a Pegasus, each with its own solid propulsion stage for injection into an interplanetary intercept orbit with a different near Earth body. Mission durations range from as little as 4 - 6 months to about 2 years depending on the target, with launch opportunities occurring at least once per year.



Development of MMIC Technology
for SATCOM Applications

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ABSTRACT

MMIC technology enables reduction of the size, weight, and cost of satellite systems. We have developed a family of Gallium Arsenide-based monolithic upconverters and downconverters for use in satellite systems such as ATDRSS, Milstar, and Brilliant Pebbles. The trend is toward the development of more complex multifunctional integrated circuits (MFICs) to reduce parts count, improve reliability, and reduce assembly and tune costs. We have demonstrated signal chip transceivers which integrate seven functions. More advanced heterojunction technologies are being developed to improve performance. Indium phosphide-based MMICs are being developed for NASA LeRC.

POWER SUBSYSTEM STATE-OF-THE-ART ASSESSMENT
AND MINIATURIZATION TECHNOLOGY NEEDS

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ABSTRACT

This presentation provides an overview of the present status of power subsystem components. Performance predictions for power components (sources, storage and Power Management and Distribution (PMAD)), will also be shown. These predictions establish the near term, less than 10 year, limits to power subsystem miniaturization. Micropower component technology needs to enable a microspacecraft power subsystem are outlined.

Sources include mini Radioisotope Thermoelectric Generators (RTGs) and solar cell technologies including: silicon, gallium arsenide, germanium and band gap. Energy storage elements include embeddable microbatteries consisting of a limited number of cells. PMAD concepts address the single chip power system and single chip power converters.

THE APPLICATION OF MICROTECHNOLOGY TO SPACECRAFT ON-BOARD COMPUTING

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ABSTRACT

The recent focus and concern for smaller, less costly missions, has given further impetus for the development of microspacecraft. Microtechnology advances in the areas of sensors, propulsion systems, and instruments, make the notion of a specialized miniature spacecraft feasible in the immediate future. However, all of the spacecraft subsystems have to rely on existing on-board computing and data processing technology which is still characterized by high mass, volume, and power consumption. Moreover, the performance of current on-board computers may also pose a constraint on mission capability and scientific return.

In this report, we will survey recent advances in chip packaging and stacking techniques that allow miniature computers to be developed for space applications. Several orders of magnitude in mass, volume and power consumption are possible using these techniques. Moreover, performance improvements can be achieved by increasing the scale of multiprocessing. Most importantly, long-term survivability can potentially be improved by increasing the level of redundancy and fault tolerance.

ELECTRONIC PACKAGING FOR MICROSPACECRAFT APPLICATIONS

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ABSTRACT

The intent of this presentation is to give a brief look into the future of electronic packaging for microspacecraft applications. Advancements in electronic packaging technology areas have developed to the point where a system engineer's visions, concepts and requirements for a microspacecraft can now be a reality. These new developments are ideal candidates for microspacecraft applications. These technologies are capable of bringing about major changes in how we design future spacecraft while taking advantage of the benefits due to size, weight, power, performance, reliability and cost. This presentation will also cover some advantages and limitations of surface mount technology (SMT), multi-chip modules (MCM) and wafer scale integration (WSI), and what is needed to implement these technologies into microspacecraft.

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Microspacecraft Attitude Control

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ABSTRACT

The essential requirement on a microspacecraft attitude control subsystem (ACS) is that it must provide a means of affecting the orientation of the spacecraft bus. Thus, it must be capable of delivering adequate torque for some finite interval of time through appropriate actuators. This clearly limits the applicable technologies and the degree to which certain key components can be miniaturized. Beside actuators, other basic components include sensors, electronics and a command and data subsystem interface. Depending on the choice of realization and the desired level of onboard autonomy, a computer may also be included. In the case of the sensors, accuracy capabilities are governed by the allowable size and mass of the package. In the case of the computer, power, as well as size and mass are limiting. The expected ACS subsystem requirements of a generic microspacecraft will be examined. These will then be discussed in the context of what is both feasible and technologically achievable. Fundamental limits and major development needs will be identified.

Lightweight Structures and Mechanisms for Microsatellites

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For small lightweight satellites, Martin Marietta is investigating several structure technologies including monocoque composite shell structures, high conductivity composite thermal management systems, thin film photovoltaic, and innovative mechanisms. Of particular importance are mechanisms because as the overall spacecraft size decreases, the size of the mechanisms remains constant. These mechanisms including door actuators, deployment devices, release devices and electrical connectors can constitute a major portion of the total spacecraft weight. Martin Marietta has developed and fabricated several innovative mechanisms using shape memory alloys (SMA). In many cases, complex gear/motor/cable actuation systems can be replaced with a single small diameter SMA wire. Thus, significant weight reductions and the space for the mechanism can be achieved using SMA. In addition, SMA mechanisms contain significantly less parts and should decrease touch labor and the associated cost while improving reliability by reducing the number of interaction parts which may fail. Technical issues under investigation are synchronization of the SMA devices and actuation frequency, which is dependent on the rate of heat application and removal.

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